FORM PTO-1390 (REV. 9-2001) U S DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY 'S DOCKET NUMBER: 14074-1"US"

U S APPLICATION NO (If known, see 37 CFR 1 5): 09/937936

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/CA 99/00290	1 April 1999	1 April 1999

TITLE OF INVENTION: HIGH PERFORMANCE BRUSHLESS MOTOR AND DRIVE FOR AN ELECTRICAL VEHICLE MOTORIZATION

APPLICANT(S) FOR DO/EO/US: Jean-Yves Dube, Jerome Cross and Philippe Viarouge

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. [X] This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. [ ] This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. [X] This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4. [X] The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. [X] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. [X] is attached hereto (required only if not communicated by the International Bureau).
   b. [ ] has been communicated by the International Bureau.
   c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US).
6. [ ] An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. [ ] is attached hereto.
   b. [ ] has been previously submitted under 35 U.S.C. 154(d)(4).
7. [X] Amendments to the claims of the International Aplication under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. [X] are attached hereto (required only if not communicated by the International Bureau).
   b. [ ] have been communicated by the International Bureau.
   c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
   d. [ ] have not been made and will not be made.
8. [ ] An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371 (c)(3)).
9. [ ] An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)).
10. [X] An English lanugage translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

Items 11 to 20 below concern document(s) or information included:

11. [ ] An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. [X] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. [X] A FIRST preliminary amendment.
14. [ ] A SECOND or SUBSEQUENT preliminary amendment.
15. [ ] A substitute specification.
16. [ ] A change of power of attorney and/or address letter.
17. [ ] A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
18. [ ] A second copy of the published international application under 35 U.S.C. 154(d)(4).
19. [ ] A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20. [X] Other items or information: Correspondence Address and Notice of Filing Without a Declaration; Notification of Transmittal of International Preliminary Examination Report; International Preliminary Examination Report; Amended Specification (pp 4, 4a, 7, 9 & 10) / Claims 1-10 / Drawings Sheets 1/10 & 2/10.

EXPRESS MAIL NO. ET178658915US
October 1, 2001

U.S. APPLICATION NO (if known, see 37 CFR 1.5)	INTERNATIONAL APPLICATION NO	ATTORNEY'S DOCKET NUMBER
09/937936	PCT/CA 99/00290	14074-1"US"

21. [X] The following fees are submitted:	CALCULATIONS PTO USE ONLY	
BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):		
Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO **$1000.00**		
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO ..... $890. ~~$860.00~~		
International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO **$710.00**		
International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) **$690.00**		
International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) **$100.00**		
ENTER APPROPRIATE BASIC FEE AMOUNT =	$ 890.00	
Surcharge of **$130.00** for furnishing the oath or declaration later than [ ] 20 [X] 30 months from the earliest claimed priority date (37 CFR 1.492(e)).	$ 130.00	

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	11 - 20 =		x **$18.00**	$	
Independent claims	4 - 3 =	1	x ~~$80.00~~ 84	$ 84.00	
MULTIPLE DEPENDENT CLAIM(S) (if applicable)			+ **$270.00**	$	
TOTAL OF ABOVE CALCULATIONS =				$ 1,104.00	
[X] Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2.			+	$ 552.00	
SUBTOTAL =				$ 552.00	
Processing fee of **$130.00** for furnishing the English translation later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(f)).				$	
TOTAL NATIONAL FEE =				$ 552.00	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property +				$ 40.00	
TOTAL FEES ENCLOSED =				$ 592.00	
				Amount to be refunded:	$
				charged:	$

a. [X] A check in the amount of $ 592.00 to cover the above fees is enclosed.

b. [ ] Please charge my Deposit Account No. _____ in the amount of $ _____ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. [ ] The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. _____. A duplicate copy of this sheet is enclosed.

d. [ ] Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137 (a) or (b)) must be filed and granted to restore the application to pending status.

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DAVID M. CARTER
NAME

26,407
REGISTRATION NUMBER

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of

Jean-Yves Dubé et al

Serial No.: Group Art Unit:

Filed: February 2, 2000 Examiner:

For: HIGH PERFORMANCE BRUSHLESS MOTOR AND DRIVE FOR AN ELECTRICAL VEHICLE MOTORIZATION

International Appl. No.: PCT/CA 99/00290

Docket No.: 14074-1"US" Asheville, North Carolina
October 1, 2001

PRELIMINARY AMENDMENT

"Express Mail" No.: ET178658915US
Date of Deposit: October 1, 2001

I hereby certify that this correspondence, paper or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR 1.10 on the date indicated above and is addressed to the Assistant Commissioner for Patents, Washington, D.C. 20231.

David M. Carter
(Typed or printed name of person mailing)

(Signature of person mailing)

Assistant Commissioner
for Patents
Washington, DC 20231

Dear Sir:

Prior to the examination of this Application, kindly amend this application as follows:

In the Amended Claims:

3. (Amended) A brushless DC motor/generator (10) as claimed in claim 1 characterized in that a multiple combination of additions of the number of said twenty-two poles and said twenty-four slots (18), such as forty-four said poles and forty-

eight said slots, or sixty-six said poles and seventy-two said slots or ninety-six said poles and eighty-eight said slots; and a wound winding (7) around said teeth (23) with one of either one coil per slot or two coils per slot.

4. (Amended) A brushless DC motor/generator (10) as claimed in claim 1 characterized in that there are three Hall sensors (24) are mounted near said air gap (25) at predetermined positions and fixed to or side some of said teeth (23).

8. (Amended) A brushless DC Motor/generator (10) as claimed in claim 1 characterized in that said motor (10) is also used as a wheel braking device when used in a generator mode, said rotor (19) being connected to a hub (52) of a wheel (53) powered by said motor (10) when in a motorized mode.

9. (Amended) A brushless DC Motor/generator (10) as claimed in claim 1 characterized in that said control circuit means (14) comprises: a power electronics three phase inverter (28) provided with six power mosfets (30), a current control system (14) coupled to said inverter (28) for generation 120 electrical degrees rectangular phase current pulses, an electronic control system (32) for both a motor and a generator

operation mode of said motor (10) and using a single switch modulation technique.

Add the following New Claims:

11. A brushless DC motor/generator (10) as claimed in claim 2 characterized in that a multiple combination of additions of the number of said twenty-two poles and said twenty-four slots (18), such as forty-four said poles and forty-eight said slots, or sixty-six said poles and seventy-two said slots or ninety-six said poles and eighty-eight said slots; and a wound winding (7) around said teeth (23) with one of either one coil per slot or two coils per slot.

12. A brushless DC motor/generator (10) as claimed in claim 2 characterized in that there are three Hall sensors (24) are mounted near said air gap (25) at predetermined positions and fixed to or side some of said teeth (23).

13. A brushless DC Motor/generator (10) as claimed in claim 2 characterized in that said motor (10) is also used as a wheel braking device when used in a generator mode, said rotor (19) being connected to a hub (52) of a wheel (53) powered by said motor (10) when in a motorized mode.

14. A brushless DC Motor/generator (10) as claimed in claim 2 characterized in that said control circuit means (14) comprises: a power electronics three phase inverter (28) provided with six power mosfets (30), a current control system (14) coupled to said inverter (28) for generation 120 electrical degrees rectangular phase current pulses, an electronic control system (32) for both a motor and a generator operation mode of said motor (10) and using a single switch modulation technique.

REMARKS

In order to reduce the filing fee, Applicant have amended claims 3, 4, 8 and 9 by eliminating their multiple dependencies, as well as a minor typographical error. Applicants have also added four new claims.

Respectfully submitted,

By: _____
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C:\DMC\AMEND\JYD-1.PRE

MARKED-UP VERSION

In the Claims:

3. (Amended) A brushless DC motor/generator (10) as claimed in claim 1 [or 2] characterized in that a multiple combination of additions of the number of said twenty-two poles and said twenty-four slots (18), such as forty-four said poles and forty-eight said slots, or sixty-six said poles and seventy-two said slots or [ninenty-six] ninety-six said poles and eighty-eight said slots; and a wound winding (7) around said teeth (23) with one of either one coil per slot or two coils per slot.

4. (Amended) A brushless DC motor/generator (10) as claimed in claim 1 [or 2] characterized in that there are three Hall sensors (24) are mounted near said air gap (25) at predetermined positions and fixed to or side some of said teeth (23).

8. (Amended) A brushless DC Motor/generator (10) as claimed in claim 1 [or 2] characterized in that said motor (10) is also used as a wheel braking device when used in a generator mode, said rotor (19) being connected to a hub (52) of a wheel (53) powered by said motor (10) when in a motorized mode.

9. (Amended) A brushless DC Motor/generator (10) as claimed in claim 1 [or 2] characterized in that said control circuit means (14) comprises: a power electronics three phase inverter (28) provided with six power mosfets (30), a current control system (14) coupled to said inverter (28) for generation 120 electrical degrees rectangular phase current pulses, an electronic control system (32) for both a motor and a generator operation mode of said motor (10) and using a single switch modulation technique.

HIGH PERFORMANCE BRUSHLESS MOTOR AND DRIVE FOR AN ELECTRICAL VEHICLE MOTORIZATION

BACKGROUND OF THE INVENTION

The present invention relates to a low cost electric system composed of a new DC brushless permanent magnet motor and its electronic drive which provides high efficiency operation and low torque ripple for the motorization of electric vehicles like, bicycles, rolling chairs, scooters, tricycles, golf cars, trolleys and small utility vehicles.

The motor and its electronic system are supplied by one or several batteries. The vehicle wheel drive can be direct to maximize efficiency or equipped with a speed reducer to minimize the motor size. The proposed solution uses a permanent magnet three-phase motor which can reach four times the nominal torque. This motor structure includes an outer rotor which can be fitted into a vehicle wheel. It can be used as motor or generator with energy recuperation in the battery during braking periods or to create electricity to recharge battery, or power other devices by changing the motor. This motor structure is supplied by a PWM (Pulse Width Modulation) current controlled inverter. The operator can impose the machine torque level in motor or generator operation by setting a current reference. The shape of the alternative phase current waveform is rectangular with a width of 120 electrical degrees. This kind of motor supply is the simplest to realize and it reduces the cost of the control system and the number of sensors.

The brushless motor includes a cylindrical outer rotor wherein permanent magnets are mounted on the surface and an internal stator with coils of insulated wire wound around the teeth. There are twenty two magnet poles on the rotor alternatively magnetized north and south and twenty-four slots on the stator. This combination of slots and poles for a three-phase motor structure allows the realization of a special concentrated winding around the teeth with only one coil per slot. In this case, there are only twelve coils to realize. The winding coefficient and the copper filling factor are higher than in the other known solutions described by Konecny U.S. Pat. No. 4,774,428, Huang and al. U.S. Pat. No. 5,675,196 and Katsuma and al. U.S. Pat. No. 4,719,378 which are using winding with two coils per slot.

This kind of winding with one coil per slot simplifies the assembling of the rotor position sensors (i.e. hall detectors) near the air gap. The hall detector are fixed on the side of several teeth which have no winding and they are using the leakage flux of the permanent magnets to detect the rotor position.

The proposed structure maximizes the energy efficiency and the motor starting torque per unit volume of winding. The advantages of a concentrated winding around the teeth in comparison with a classical distributed winding are described in Konecny U.S. Pat. No. 4,774,428 and Permanent magnet Brushless DC motor with soft metal powder for automotive application – J. Cros, P. Viarouge IEEE Industry applications Society – St-Louis , October 1998. [1]. The volume of copper is reduced and subsequently the Joule losses are minimized.

The amount of vibrations and the cogging torque ripple are reduced drastically like in the other structure combinations described by Konecny U.S. Pat. No. 4,774,428, Huang and al. U.S. Pat. No. 5,675,196 and Katsuma and al. U.S. Pat. No. 4,719,378. The least common multiple (LCM) of the motor's poles and slots describes how many peaks of cogging torque will be present over a single revolution of the motor. In this case, there are 264 torque pulses per revolution and consequently, the cogging torque amplitude is very low (less than 3% of the rated torque).

The proposed motor structure also minimizes the net radial force like another structure described by Huang and al. U.S. Pat. No. 5,675,196.

The electronic supply includes a power electronics system and a control electronics system. Both systems can be inserted inside the motor housing, in the center of the stator yoke. The power electronics system is composed of an inverter with six Mosfets or multiple Mosfets which operate like six Mosfets. The structure diodes of the mosfets are used to ensure the current reversibility. At each sequence of conduction defined by the rotor position detector, two transistors are switched on to supply two motor phases. In the classical mode of operation, a modulation signal is applied on the gate of these two

system. Both systems can be inserted inside the motor housing, in the center of the stator yoke. The power electronics system is composed of an inverter with six Mosfets or multiple Mosfets which operate like six Mosfets. The structure diodes of the mosfets are used to ensure the current reversibility. At each sequence of conduction defined by the rotor position detector, two transistors are switched on to supply two motor phases. In the classical mode of operation, a modulation signal is applied on the gate of these two transistors. This method simplifies the control realization and only one current sensor can be inserted in the DC bus for the current measurement.

Another solution consists in applying the modulation signal on one transistor only at each sequence of operation: this method is the single switch modulation technique. The other transistor is switched "on" during all the duration of this sequence of conduction. This mode of operation is described in E.M.I. tests on a brushless actuator: Comparison of M. Lajoie-Mazene, J.P. Berry – European Power Electronics – Brighton (U.K.), September 1993 [2], in the case of motoring operation only, compared to the classical mode of operation where the modulation signal is applied on the gate of the two transistors. It is shown that the single switch modulation provides lower electromagnetic interferences (EMI) and reduces the commutation losses, the conduction losses in low voltage applications, the current ripple and the size of the input filtering capacitor. The proposed electronic system is using the single switch modulation and it can be used for motor as well as generator operation. Consequently, the current regulation is realized without any external current sensor.

SUMMARY OF THE INVENTION

It is a feature of the present invention to provide a high performance brushless DC permanent magnet motor and a pulse width modulation electronic inverter for the motorization of electric vehicles supplied with electrical batteries. The motor structure includes an outer rotor which can be fitted to a vehicle wheel. It can be used as a motor or as a generator with recuperation of kinetic energy in the batteries during braking periods.

Another feature of the invention is to provide a special design and the design of its three-phase winding maximize the energy efficiency and the motor starting torque per unit volume of winding. A concentrated winding is wound around the teeth with only one coil per slot. This solution simplifies the winding realization and maximizes the winding coefficient and the copper filling factor.

Another feature of the invention is that the assembling of the rotor position sensor (i.e. hall detectors) near the air gap is simplified by the winding configuration. The hall detector are fixed on the side of several teeth which have no winding and they are using the leakage flux of the permanent magnets to detect the rotor position. The amount of vibrations, the cogging torque ripple and the radial force are greatly reduced.

Another feature of the invention is to provide specific inverter control system which reduces the commutation losses, the diode conduction losses in low voltage applications, the current ripple, the size of the input filtering capacitor and electromagnetic interference. A specific single switch modulation technique is used: The modulation signal is applied only on one transistor at each sequence of operation defined by the rotor position detector. The other transistor is switched on during all the duration of this sequence of conduction. This single switch modulation method maximizes the efficiency of the electronic supply and the current regulation is realized without any external current sensor.

According to the above features, from a broad aspect, the present invention provides a brushless DC motor for electrical vehicle motorization. The motor comprises a cylindrical rotor with 22 poles constructed with segments of permanent magnet material alternatively magnetized north and south. A stator core of ferromagnetic material is spaced inwardly of the rotor and defines a magnetic clearance gap therebetween. The stator core has twenty four slots and define teeth between the slots. A three-phase winding with coils of insulated wire is wound around the teeth. There is provided one coil per slot with predetermined connection patterns A', C, C, B', B', A, A, C', C', B, B, and A' resulting in reduced torque ripple without any slot or magnet skewing.

According to a still further broad aspect of the present invention there is provided a brushless DC motor as above described but wherein there is further provided two coils per slot having predetermined connection patterns C', C, C', C, B, B', B, B', A', A, A', A, C, C', C, C', B', B, B', B, A, A', A, A'.

According to a still further broad aspect of the present invention there is provided a brushless DC motor electronic pulse with modulation driver and control system. It includes a power electronic three phase inverter having six power of mosfets. A current control system is coupled to the inverter for generating a 120 electrical degrees rectangular phase current pulses. An electronic control system is provided for both motor and a generator operation mode of the motor and uses a single switch modulation technique.

According to a still further broad aspect of the present invention there is provided a brushless DC motor for breaking a wheel of devices on which people are displaced by self-motorization or electric motor motorization. The motor comprises a cylindrical rotor with twenty two poles constructed with segments of permanent magnet material alternatively magnetized north and south, a stator core of ferromagnetic material spaced inwardly of said rotor and defining a magnetic clearance gap, therebetween said stator core having twenty-four slots and defining teeth between said slots, a three phase winding with coils of insulated wire being wound around the teeth. The rotor is connected to a hub of the wheel. Control circuit means is provided to control the torque of the motor and therefore its arresting force.

BRIEF DESCRIPTION OF THE DRAWING

A preferred embodiment of the present invention will now be described with reference to the accompanying drawings in which:

Fig. 1 is a schematic diagram of a brushless DC motor structure including a motor, a power electronics system and a current control system;

Fig.2 is a diagrammatic view of the twenty-two pole rotor and the twenty-four slot stator arrangement in accordance with principles of the present invention;

Fig 3 is a first coil winding diagram arrangement with one coil per slot;

Fig 4 is a second coil winding arrangement with two coils per slot;

Fig 5 indicates the position of the three Hall sensors in the motor which are used to detect the rotor position;

Fig 6 is a simplified diagram of the electronic system (power electronics system (inverter) and control system);

Fig 7 shows the conduction sequence order of the power mosfets;

Fig 8 shows the simplified waveforms of the phase current and phase emf of the;

Fig 9 shows the diagram of the mosfet control signals during one period of the motor operation mode;

Fig 10 indicates the current flow in the case of the sequence (T1 – T2) in motor operation mode;

Fig 11 is a diagram of the mosfet control signals during one period of the generator operation mode;

Fig 12 indicates the current flow in the case of the sequence (T1 – T2) in generator operation mode;

Figure 13 shows a schematic view of the current control;

Figure 14 is a schematic diagram of the transformation of the signals of the rotor position sensors and the generation of the mosfet gate control signals in motor operation mode;

Figure 15 is a schematic diagram of the electronic system for the generation, the mosfet gate control signals, and the measurement of the phase current in the motor and generator operation mode with the single switch modulation technique, and

Figure 16 is a simplified fragmented side view showing the motor of the present invention coupled to a wheel of a bicycle through its rotor.

DETAILED DESCRIPTION OF THE INVENTION

In electrical vehicle applications, it is necessary to produce high starting torque and to ensure variable speed in both motor and generator modes of operation. The use of a brushless DC motor is particularly well adapted to this kind of applications. To reduce the cost of the electronic system and the number of sensors, it is better to supply the motor winding phases with a rectangular waveform current. The motor torque is

controlled by a simple current regulation and the phase voltage is chopped with a pulse width modulation technique (PWM). The schematic diagram of this kind of brushless DC motor is presented on Fig.1. It includes a permanent magnet motor 10, a power electronic supply 11, a rotor position detector 12, a current measurement system 13 and a current regulation system which is comprised of a current control circuit 14 fed by the current measuring circuit 13 and a torque reference or current reference circuit 16. The current control circuit 14 is connected to the power electric supply circuit 11 to control the torque of the motor 10. The system can be used for motor or generator operation with energy recuperation on the battery 15 during braking periods.

As shown in Fig. 2, the proposed solution in the present invention is to use a motor 10 structure having a twenty-two poles and twenty-four slots 18 with a cylindrical outer rotor 19. Permanent magnets 20 are mounted on the rotor inner surface 21 and altenatively magnetized north and south. The high number of poles reduces the iron volume and provides acceptable iron losses when the speed is less than 1,000 rpm.

As shown in Fig's 3 and 4, a concentrated winding 22 is wound around the teeth 23. The advantages of a concentrated winding around the teeth in comparison with a classical distributed winding are described in Konecny U.S. Pat. No. 4,774,428 and the article reference E.M.I tests on a brushless actuator: Comparison of different operation modes- J. Cros, S. Astier, J.M. Vinassa, M. Lajoie-Mazenc, J.P. Berry– European Power Electronics – Brighton (UK), September 1993. [1]. The volume of copper is reduced and subsequently the Joule losses are minimized. The energy efficiency and the motor starting torque per unit volume of winding are maximized.

A first winding configuration with only one coil per slot, as shown in Fig. 3, maximizes the winding coefficient (0.958) and the slot filling factor and simplifies the winding realization. An alternative winding configuration with two coils per slots is presented on Fig 4 and it can be used for the proposed motor structure (winding coefficient : 0.949). Referring now to Fig. 5, the assembling of the rotor position sensor, i.e. Hall detectors 24, near the air gap 25, is simplified by the winding configuration of Fig. 3, using one coil per slot . The Hall detectors 24 are fixed on the side of several teeth 23 which have no

winding, such as teeth 23' in Fig. 3, and they are using the leakage flux of the permanent magnets to detect the rotor position. Hall sensors or detectors 24 are placed to position the phase current and the phase electromagnetic force (back emf) waveforms like in Fig's 7 & 8. The maximum value of the torque to current ratio is then obtained with this configuration.

The cogging torque ripple are greatly reduced without any slot skewing, as in the other structure combinations described by Konecny U.S. Pat. No. 4,774,428, Huang and al. U.S. Pat. No. 5,675,196 and Katsuma and al. U.S. Pat. No. 4,719,378. The least common multiple (LCM) of the motor's poles and slots describes how many peaks of cogging torque will be present over a single revolution of the motor. In this case, there are 264 torque pulses per revolution and consequently, the cogging torque amplitude is very low (less than 3% of the rated torque). The proposed motor structure also minimizes the net radial force like another structure described by Huang and al. U.S. Pat. No. 5,675,196.

Referring now to Fig. 6 there is shown the electronic supply which includes a power electronics system and a low power control electronics system. Both systems can be inserted in the cavity 26 inside the motor housing, in the center of the stator yoke 27. The power electronics system is a six switches, PWM (pulse width modulation) inverter 26. Six type N Mosfets 28 (T1, T2, T3, T'1, T'2, T'3) are used and the structure diodes of the mosfets 29 are used to ensure the current reversibility. The electronic system also includes a push-pull driver 30 for each mosfet, three boostrap supplies 31 feed the driver stages of the three transistors T'1, T'2, T'3 of the upper side of the inverter 28 and three level–shift control signals are applied to the driver stages of transistor T'1, T'2, T'3.

A current regulation circuit 32 generates a PWM signal at each transistor control signal. The voltages of the power mosfets 29' T1, T2, T3 on the lower side 28' of the inverter 28 are used to measure the motor currents. The rotor position sensors 24 define the conduction sequence order and are also used to select the voltage of the power mosfet 29 in conduction to be sensed by means of a multiplexer 33 with 3 inputs 33' and 1 output 33". The multiplexer 33 is used to generate a signal equivalent to the motor current,

which can be used in the current regulation loop. The operator can select the operation mode of the system (motor or generator operation mode) and the current reference level to impose the torque of the machine.

Fig 7 presents the chronogram 37 of the conduction sequences of the power mosfets 29. At each time, there are only two Mosfets switched on. There are six sequences of operation in an electric period . During each sequence two phases of the machine are supplied. There are six current commutations when the rotor rotates with an angle of 32.7 degrees. The commutation process is controlled by the rotor position detectors 24 (i.e. Hall sensors).

Fig 8 shows the rectangular waveform 38 of the phase current which is in phase with the waveform 39 of the back electromotive force (back emf) of the same phase.

Referring now to Fig's 9 to 12., there is shown a single switch modulation technique used for both motor and generator operation. The modulation signal is only applied on the gate of the transistors of the inverter upper side (T'1, T'2, T'3) in the case of motor operation mode (see Fig 9 & 10). The transistors T1, T2, T3 remain switched "on" during all the duration of the conduction sequence. In comparison to the classical modulation technique where the modulation signal is applied to switches of both lower and upper sides. This specific single switch modulation technique provides lower commutation losses and lower conduction losses in the case of low voltage applications (the voltage drop of a power mosfet is lower than the voltage drop of a diode) see the E.M.I. tests article referred herein. The efficiency of the inverter 28 is higher. This single switch modulation technique simplifies the measurement of the phase currents and it eliminates the need of an external current sensor. The voltages of the Mosfets (T1, T2, T3) of the inverter lower side 28' can be used to measure the motor phase currents during all the sequences. In the case of the sequence T'1-T2, the voltage of transistor T2 is used to measure the motor phase current.

Fig 9 shows the control signals which are applied to the transistor gates in the case of the single switch modulation technique.

Fig 10 shows the current flow during one sequence in the motor operation mode. When transistors T'1 and T2 are switched "on" (Fig 10a), the battery supplies two phases 40 and 41 of the motor. When the transistor T'1 is switched "off", the structure diode of mosfet T1 is switched "on" and a free wheeling operation is occurring (Fig10b). The current ripple is reduced by half in comparison with the classical two-switch modulation technique. There is no current inversion in the DC bus and so the size of the filtering capacitor (not shown but well known in the art) can be reduced (lower RMS current on the DC bus). Consequently, the electromagnetic interferences are also lower than in the case of the classical modulation mode see the E.M.I. article referred herein.

Fig's 11 & 12 present the case of the generator operation mode. The upper side inverter transistors 29 T'1, T'2, T'3 are all switched "off" during the generator operation mode. Only the structure diodes of these transistors are used in this mode. A modulation signal is applied on the gate 42 of transistors T1, T2, T3 (see Fig. 6) in the lower side 28' of the inverter 28. There are some intervals where permanent conduction is occuring. They are used to measure the mosfet voltage for the current control (see Fig 12). Fig 12 shows the current flow during one sequence of operation. The machine or motor current increases when the transistors 30 T1, T2 are switched "on" (Fig 12b). When transistor T1 is switched "off", the structure diode of transistor T'1 is switched "on" and the machine supplies the battery 43 (Fig 12a).

Fig's 13 and 14 show block diagram views of a classical current regulation with a PI regulator 44 which can be applied in the case of the single switch modulation mode. The proposed electronic system for both motor and generator operation modes with the single switch modulation technique is presented on fig 15. This system includes two signal multiplexers and several AND/OR gates used to control the signals applied to the transistor driver stages and the signals of measurements of the machine current. The system is also realizable by an integrated circuit or a programmable circuit obvious to a person skilled in the art.

It is within the ambit of the present invention to cover any obvious modifications provided such modification fell within the scope of the appended claims.

Referring now to Figure 16 there is shown a brushless DC motor 50, constructed as above described, and wherein the rotor 51 is connected to a hub 52 of a wheel 53 herein a bicycle wheel. Alternatively, to reduce production cost, the motor cover housing may have connections to which the spokes of the wheel are connected to. A battery, not shown, is conveniently secured to the bicycle and power is fed to the control circuitry provided or mounted within the cavity inside the stator. A cable 54 is secured to a control device which is operated by the user of the bicycle to control the speed of the motor. This control device could be in the form of a rotating handle and grip, a hand lever device or any other convenient means. When the motor is used as a motorizing machine it drives the wheel 53. The motor can also be utilized as a break when placed in its generating mode. As previously mentioned, this motor can be secured to all sorts of electrical vehicles such as wheel chairs, scooters, tricycles, golf trolleys, small utility vehicles, etc.

We claim :

1. A brushless DC motor for electrical vehicle motorization comprising; a cylindrical rotor with twenty two poles constructed with segments of permanent magnet material alternatively magnetized north and south, a stator core of ferromagnetic material spaced inwardly of said rotor and defining a magnetic clearance gap therebetween, said stator core having twenty-four slots and defining teeth between said slots, a three phase winding with coils of insulated wire being wound around the teeth, therebeing one coil per slots with predetermined connection patterns: A', C, C, B', B', A, A, C', C', B, B, and A' resulting in reduced torque ripple without any slot or magnet skewing.

2. A brushless DC motor for electrical vehicle motorization comprising; a cylindrical rotor with twenty two poles constructed with segments of permanent magnet material alternatively magnetized north and south, a stator core of ferromagnetic material spaced inwardly of said rotor and defining a magnetic clearance gap, therebetween said stator core having twenty-four slots and defining teeth between said slots, a three phase winding with coils of insulated wire being wound around the teeth, therebeing two coils per slots with predetermined connection patterns: C', C, C', C, B, B', B, B', A', A, A', A, C, C', C, C', B', B, B', B, A, A', A, A' resulting in reduced torque ripple without any slot or magnet skewing.

3. A brushless DC motor as claimed in claim 1 or 2 having a multiple combination of additions of the number of said twenty-two poles and said twenty-four slots, such as forty-four said poles and forty-eight said slots, or sixty-six said poles and seventy-two said slots or ninety-six said poles and eighty-eight said slots; and a wound winding around said teeth with one of either one coil per slot or two coils per slot.

4. A brushless DC motor as claimed in claim 1 or 2 wherein three Hall sensors are mounted near said air gap at predetermined positions and fixed to or side some of said teeth.

5. A brushless DC motor as claimed in claim 4 having a power electronics pulse width modulation driver and control system, said pulse width modulation driver having a three phase inverter including six power mosfets, a current control system coupled to said inverter for generating 120 electrical degrees rectangular phase current pulses, said control system using a single switch modulation technique.

6. A brushless DC motor as claimed in claim 5 wherein said single switch modulation technique is comprised of three of said mosfets being connected as an upper side of said inverter and remain switched "on" by a modulation signal during a motor operation mode of said motor, three others of said mosfets being connected as a lower side of said inverter and used to measure motor phase currents during all sequences of the mosfets of said upper side.

7. A brushless DC motor as claimed in claim 6 wherein said mosfets of said upper side of said inverter are switched "off" during a generator operation mode of said DC motor, and wherein a modulation signal is applied on a gate of said three mosfets on said lower side of said inverter.

8. A brushless DC motor as claimed in claim 1 wherein said motor is also used as a wheel braking device when used in a generator mode, said rotor being connected to a hub of a wheel powered by said motor when in a motorized mode.

9. A brushless DC motor electronic pulse width modulation driver and control system comprising: a power electronics three phase inverter having six power mosfets, a current control system coupled to said inverter for generating 120 electrical degrees rectangular phase current pulses, an electronic control system for both a motor and a generator operation mode of said motor and using a single switch modulation technique.

10. An electronic control system as claimed in claim 9 wherein voltages across thereof said mosfets on a lower side of said inverter are used to generate a current measurement for the purpose of motor current control of said single switch modulation technique.

11. A brushless DC motor for braking a wheel of devices on which people are displaced by self-motorization or electric motor motorization, said motor comprising a cylindrical rotor cylindrical rotor with twenty two poles constructed with segments of permanent magnet material alternatively magnetized north and south, a stator core of ferromagnetic material spaced inwardly of said rotor and defining a magnetic clearance gap, therebetween said stator core having twenty-four slots and defining teeth between said slots, a three phase winding with coils of insulated wire being wound around the teeth said rotor being connected to a hub of said wheel, and control circuit means to control the torque of said motor and therefore its arresting force.

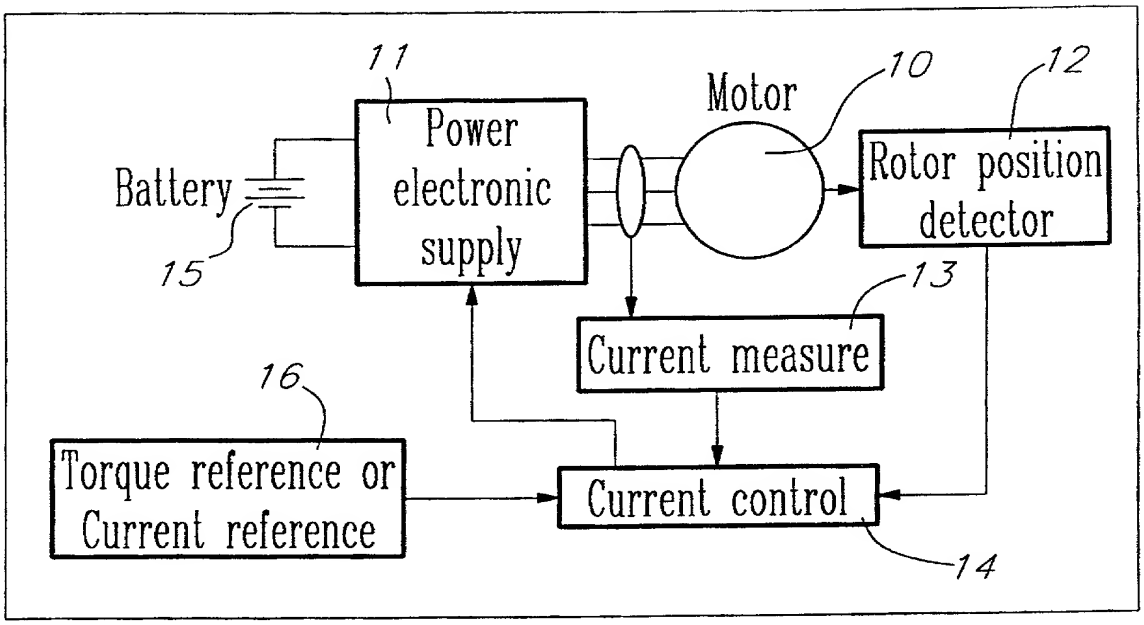

Fig - 1

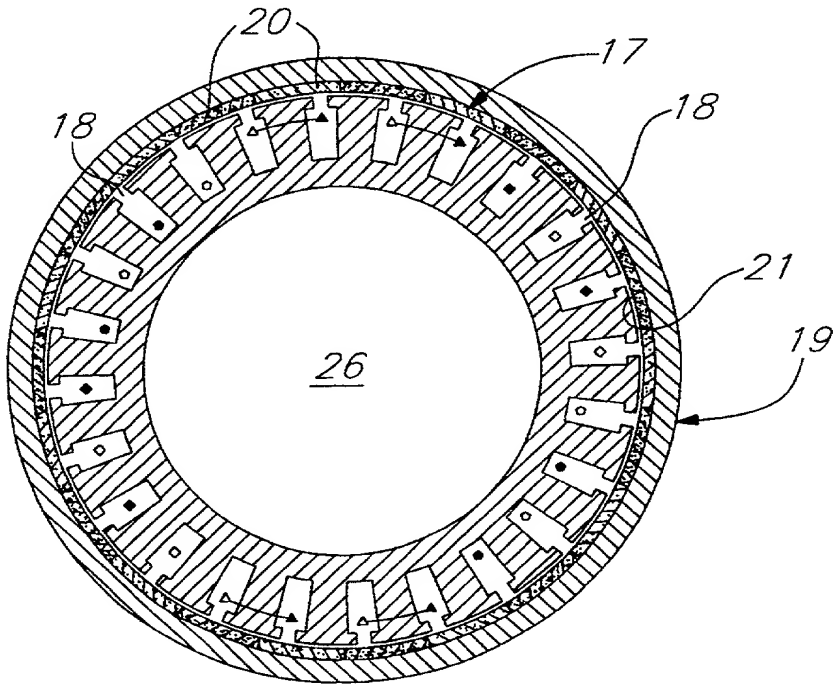

Fig - 2

09/937936

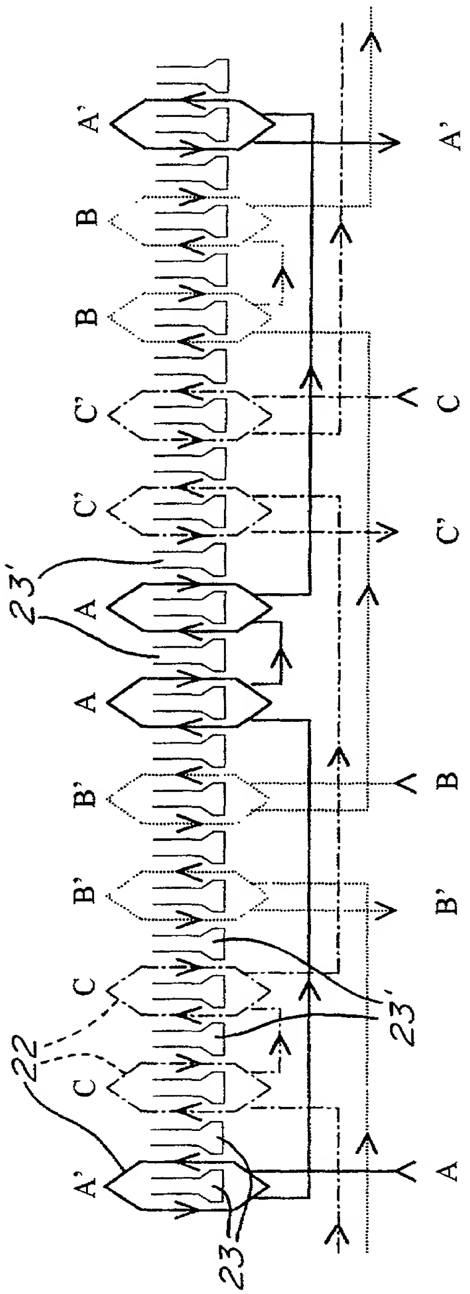

FIG. 3

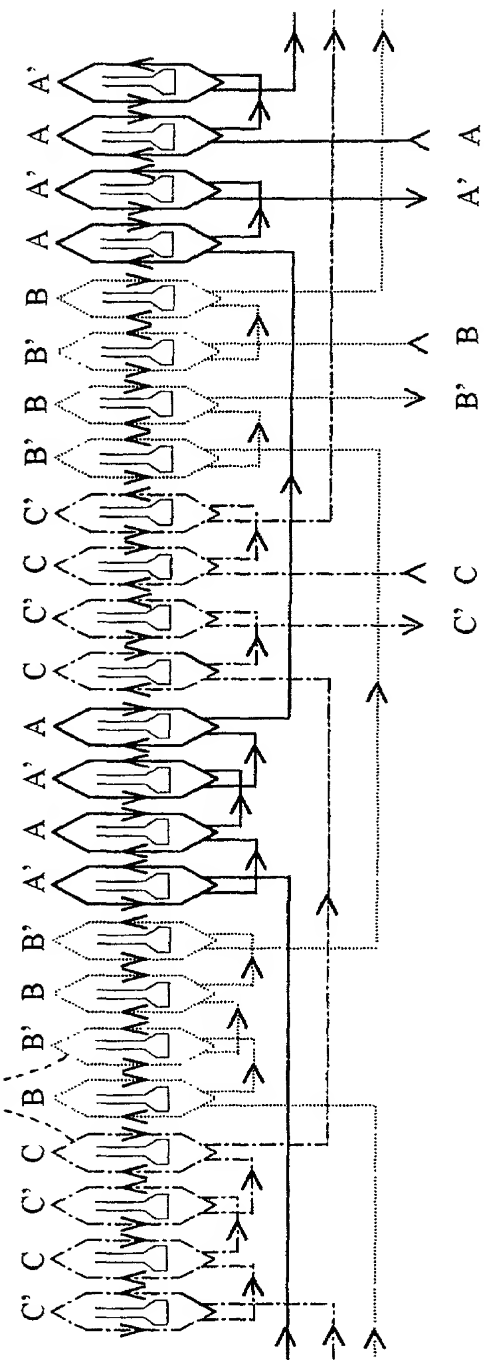

FIG. 4

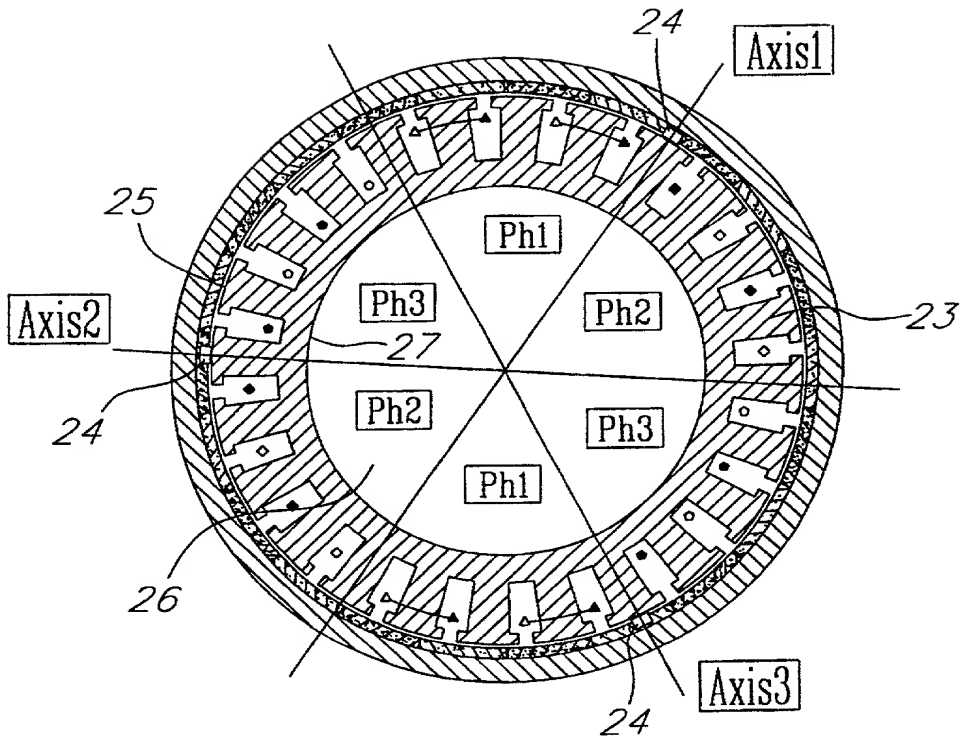

Fig - 5

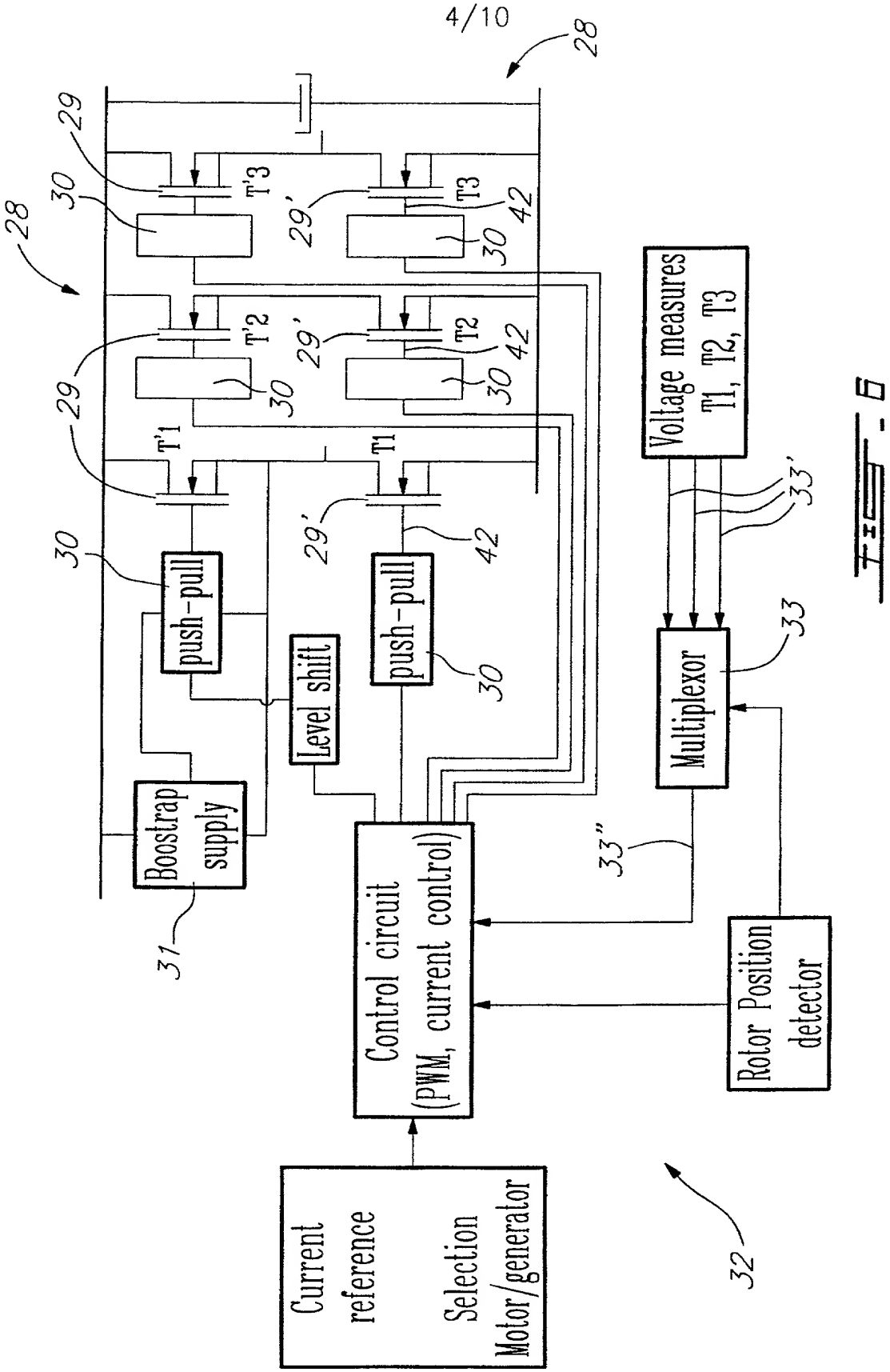
28
29
30
T'3
T3
42
29'
T'2
T2
T'1
T1
push-pull
Level shift
Boostrap supply
31
Control circuit (PWM, current control)
Current reference
Selection
Motor/generator
32
Voltage measures T1, T2, T3
33'
Multiplexor
33
33"
Rotor Position detector

Fig - 6

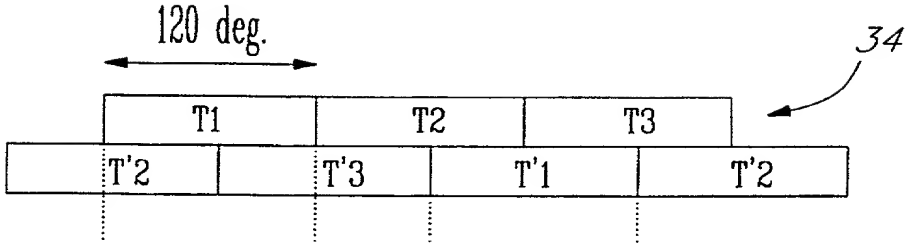

Fig. 7

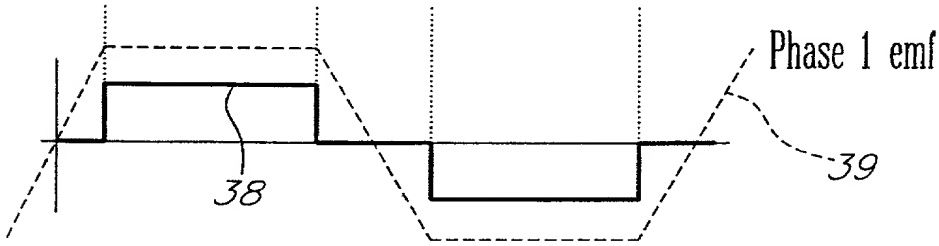

Fig. 8

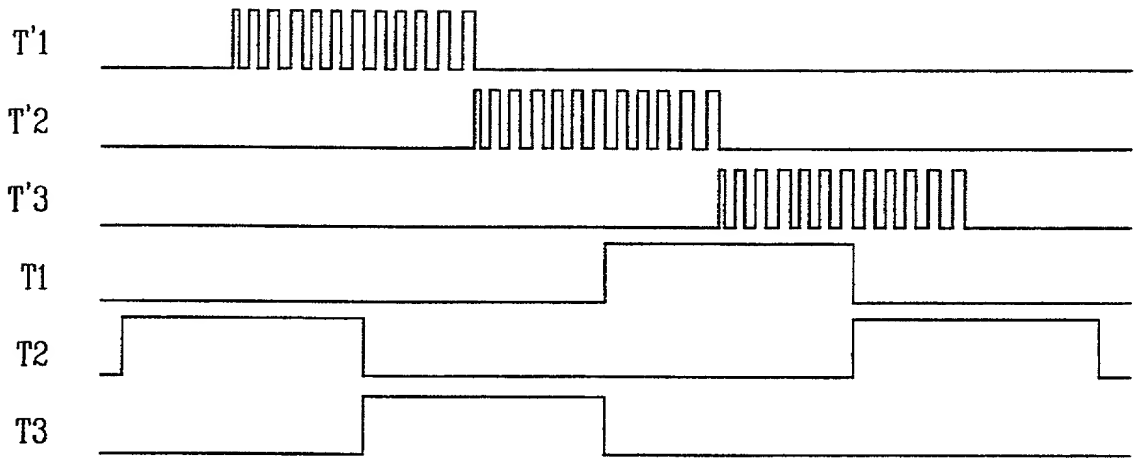

Fig 9

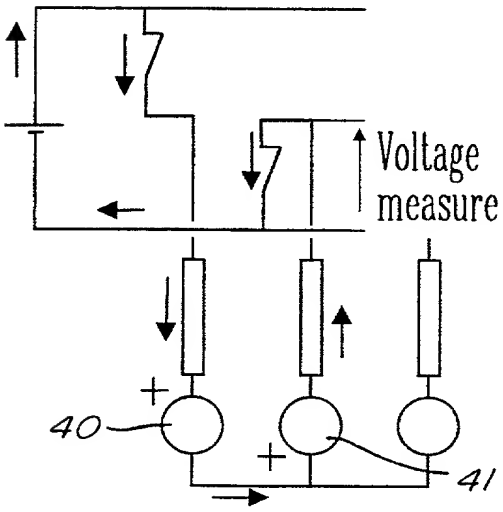

Fig 10a

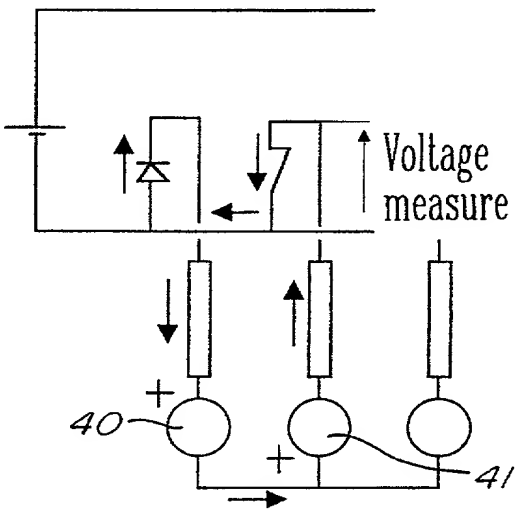

Fig 10b

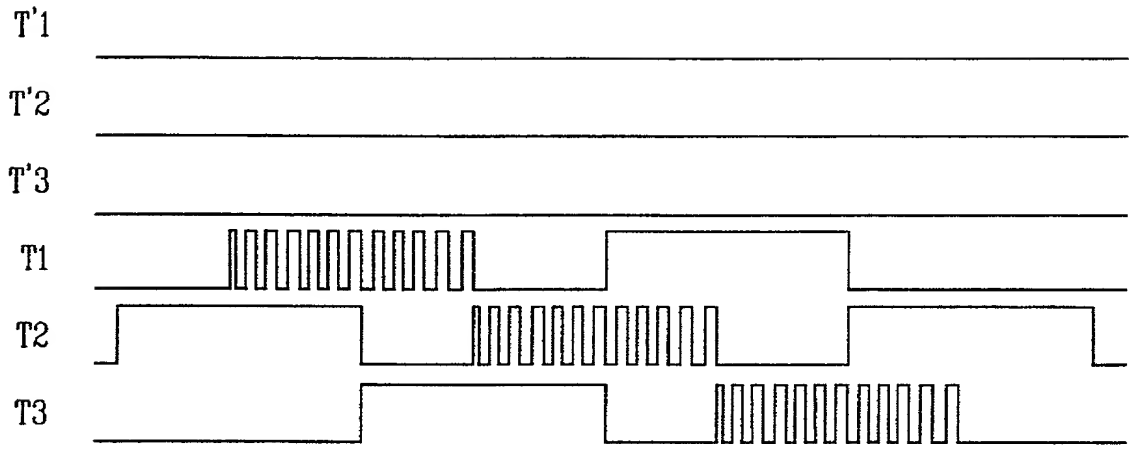

Fig - 11

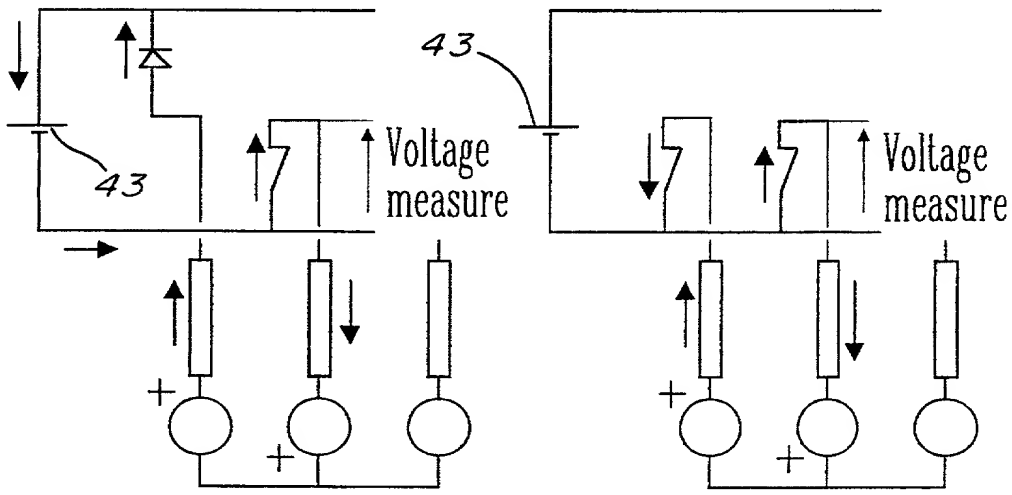

Fig - 12a Fig - 12b

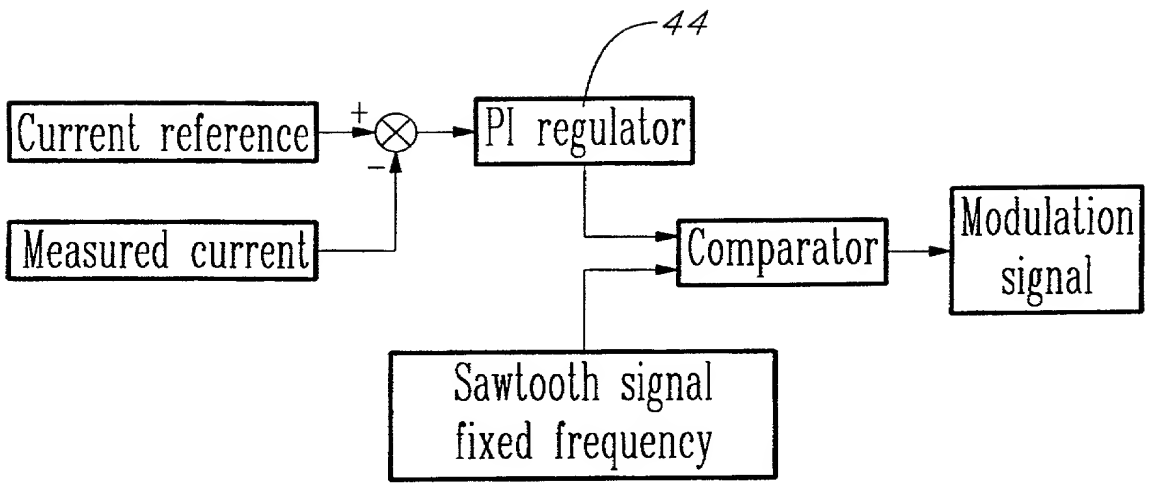
44
Current reference
+
−
PI regulator
Measured current
Comparator
Modulation signal
Sawtooth signal fixed frequency

Fig. 13

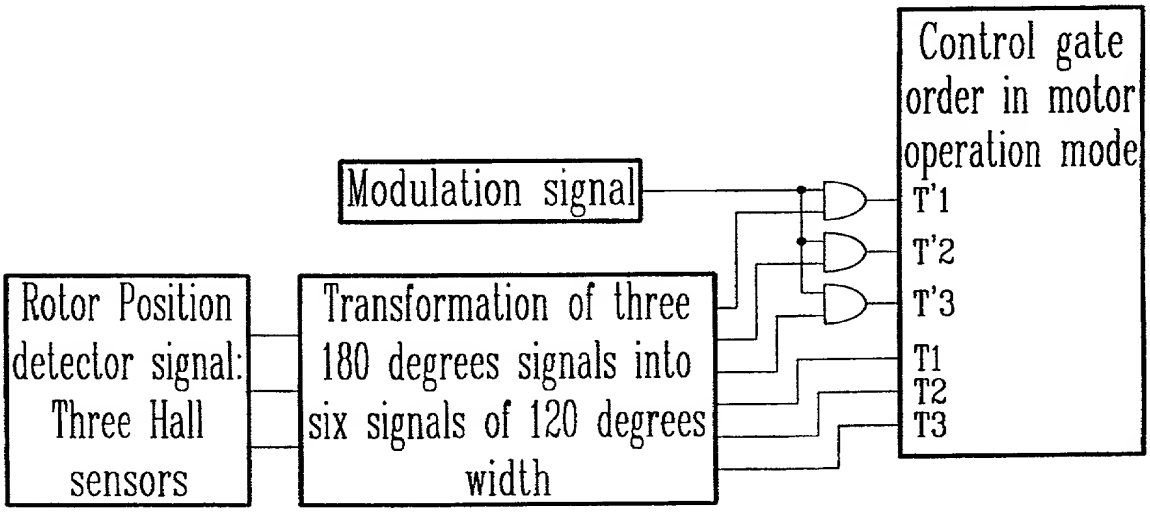
Control gate order in motor operation mode
Modulation signal
T'1
T'2
T'3
T1
T2
T3
Rotor Position detector signal: Three Hall sensors
Transformation of three 180 degrees signals into six signals of 120 degrees width

Fig. 14

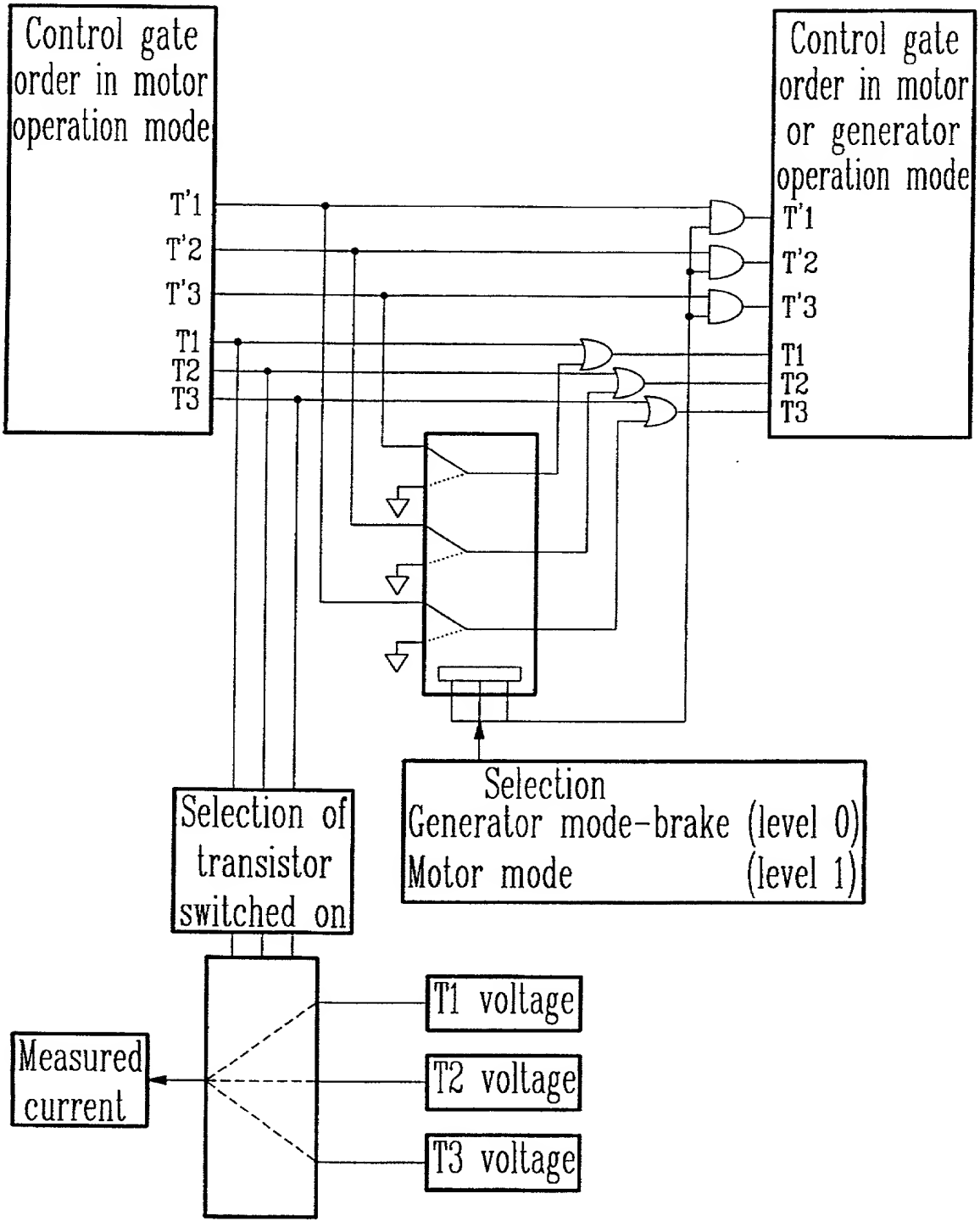

Fig. 15

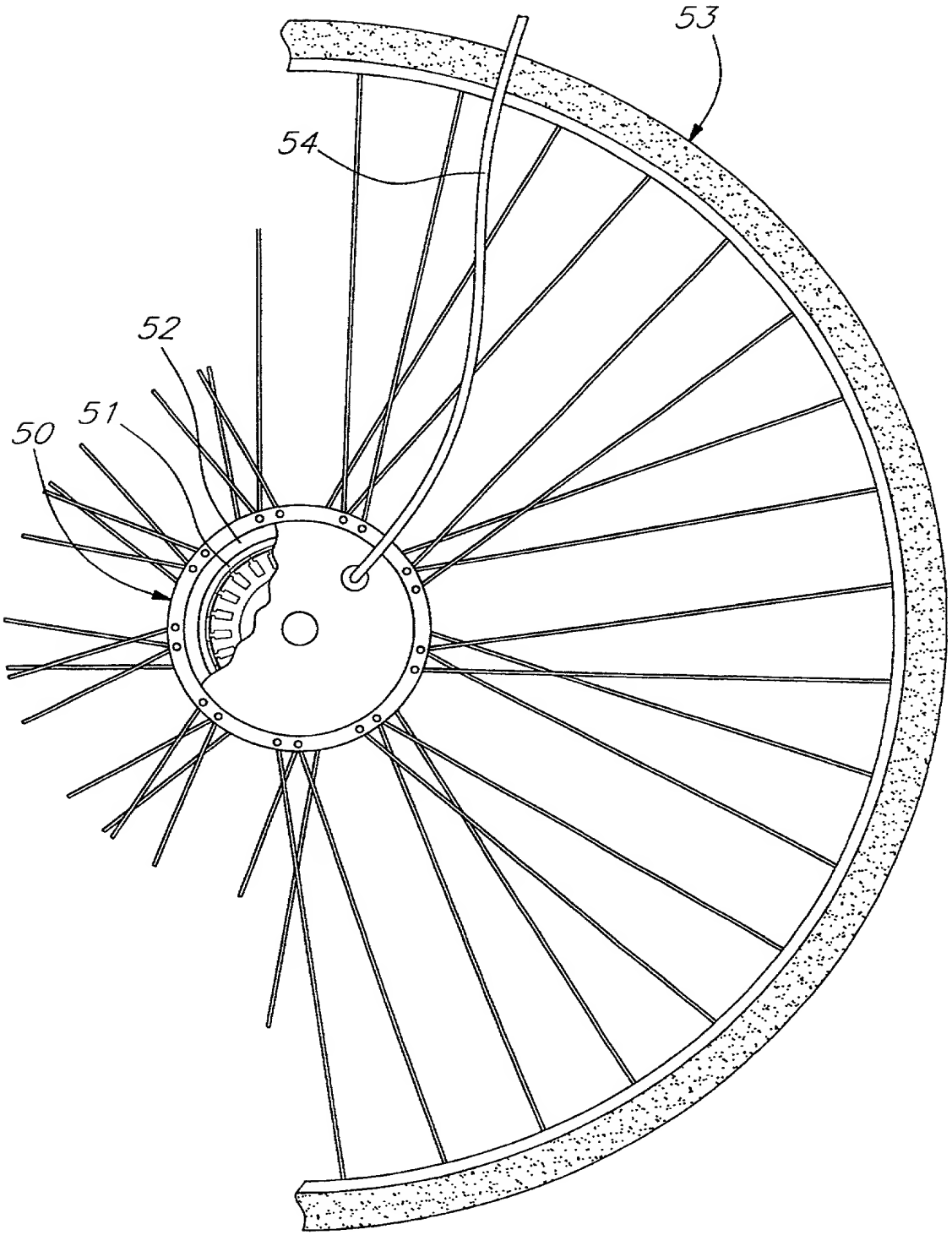

Fig. 16

Attorney Docket No. 14074-1US JA/IC

#3

Declaration and Power of Attorney for Patent Application

Déclaration et Pouvoir pour Demande de Brevet
French Language Declaration

En tant qu'inventeur ci-après désigné, je déclare par la présente que:

Mon domicile, mon adresse postale et ma nationalité sont tels que figurant ci-dessous à côté de mon nom.

Je crois être le premier inventeur original et unique (si un seul nom est mentionné ci-dessous), ou l'un des premiers co-inventeurs originaux (si plusieurs noms sont mentionnés ci-dessous) de l'objet revendiqué, pour lequel une demande de brevet a été déposée concernant l'invention intitulée

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

HIGH PERFORMANCE BRUSHLESS MOTOR AND DRIVE FOR AN ELECTRICAL VEHICLE MOTORIZATION,

et dont le mémoire descriptif est ci-joint à moins que la case suivante n'ait été cochée:

☐ a été déposée le _____ sous le numéro de demande des États-Unis ou le numéro de demande internationale PCT _____ et modifiée le _____ (le cas échéant).

the specification of which is attached hereto unless the following box is checked:

☒ was filed on April 2, 1999 as United States Application Number or PCT International Application Number PCT/CA99/00290 and was amended on January 9, 2001 and May 16, 2001 (if applicable).

Je déclare par la présente avoir révisé et compris le contenu du mémoire descriptif ci-dessus mentionné, incluant les revendications, telles que modifiées par toute modification ci-dessus mentionnée.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

Je reconnais devoir divulguer toute information pertinente à la brevetabilité, tel que défini dans le Titre 37, §1.56 du Code fédéral des réglementations.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations., §1.56.

Je revendique par la présente la priorité étrangère, en vertu du Titre 35, §119(a)-(d) ou §365(b) du Code des États-Unis, sur toute demande étrangère de brevet ou certificat d'inventeur ou, en vertu du Titre 35, §365(a) du même Code, sur toute demande internationale PCT désignant au moins un pays autre que les États-Unis et figurant ci-dessous et, en cochant la case, j'ai aussi indiqué ci-dessous toute demande étrangère de brevet, tout certificat d'inventeur ou toute demande internationale PCT

I hereby claim foreign priority under Title 35, United States Code, §119(a)-(d) or §365 (b) of any foreign application(s) for patent or inventor's certificate, or §365(a) of any PCT International application which designated at least one country other than the United States, listed below, and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application

French Language Declaration

ayant une date de dépôt précédant celle de la demande à propos de laquelle une priorité est revendiquée.

on which priority is claimed.

Prior foreign application(s)
Demande(s) de brevet antérieure(s)

Priority Not Claimed
Droit de priorité non revendiqué

(Number) (Numéro)	(Country) (Pays)	(Day/Month/Year Filed) (Jour/Mois/Année de dépôt)	☐
(Number) (Numéro)	(Country) (Pays)	(Day/Month/Year Filed) (Jour/Mois/Année de dépôt)	☐

Je revendique par la présente tout bénéfice, en vertu du Titre 35, §119(c) du Code des États-Unis, de toute demande de brevet provisoire effectuée aux États-Unis et figurant ci-dessous.

I hereby claim the benefit under Title 35, United States Code, §119(e) of any United States provisional application(s) listed below.

(Application No.) (N° de demande)	(Filing Date) (Date de dépôt)

Je revendique par la présente tout bénéfice, en vertu du Titre 35, §120 du Code des États-Unis, de toute demande de brevet effectuée aux États-Unis, ou en vertu du Titre 35, §365(c) du même Code, de toute demande internationale PCT désignant les États-Unis et figurant ci-dessous et, dans la mesure où l'objet de chacune des revendications de cette demande de brevet n'est pas divulgué dans la demande antérieure américaine ou internationale PCT, en vertu des dispositions du premier paragraphe du Titre 35, §112 du Code des États-Unis, je reconnais devoir divulguer toute information pertinente à la brevetabilité, tel que défini dans le Titre 37, §1.56 du Code fédéral des réglementations, dont j'ai pu disposer entre la date de dépôt de la demande antérieure et la date de dépôt de la demande nationale ou internationale PCT de la présente demande:

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s), or §365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, §1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

(Application No.) (N° de demande)	(Filing Date) (Date de dépôt)	(Status) (patented, pending, abandoned) (Statut) (breveté, en cours d'examen, abandonné)
(Application No.) (N° de demande)	(Filing Date) (Date de dépôt)	(Status) (patented, pending, abandoned) (Statut) (breveté, en cours d'examen, abandonné)

French Language Declaration

Je déclare que toute les déclarations faites dans la présente sont à ma connaissance, véridiques et que toutes les déclarations faites à partir de renseignements ou de suppositions sont tenues pour véridiques; et de plus, que toutes ces déclarations ont été faites en sachant que toute fausse déclaration volontaire ou son équivalent est passible d'une amende ou d'une peine d'emprisonnement, ou des deux, en vertu de la Section 1001 du Titre 18 du Code des États-Unis, et que de telles déclarations volontairement fausses risquent de compromettre la validité de la demande de brevet ou du brevet délivré à partir de celle-ci.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POUVOIR: En tant qu'inventeur désigné, Je nomme par la présente l'(les) avocat(s) et/ou agent(s) suivant(s), avec plein pouvoir de révocation et de substitution, chargés de poursuivre cette demande et de traiter toute affaire s'y rapportant avec l'Office des brevets et des marques: *(mentionner le nom et le numéro d'enregistrement).*

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following agents and/or attorneys, with full power of substitution, association, and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith: *(list name and registration number)*

(13) DAVID M. CARTER, Registration No. 26,407; STEVEN C. SCHNEDLER, Registration No. 27,591; J. DEREL MONTEITH, JR., Registration No. 45,464

and / et

JAMES ANGLEHART, Registration No. 38,796, MAX R. WOOD (Reg. No. 40,388), ROBERT MITCHELL, Registration. No. 25,007, GUY HOULE, Registration No. 24,971, PAUL MARCOUX, Registration No. 24,990, KEVIN P. MURPHY, Registration No. 26,674; ROBERT CARRIER, Registration No. 30,726; MICHEL J. SOFIA; Registration No. 37,017; NADEAU, François, Registration No. 37,570 and / et FRANCE CÔTÉ, Registration No. 37,037;

Please send all correspondence and direct all telephone calls to: / Veuillez adresser toute correspondance et tout appel téléphonique à:

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Tel. (828) 252-6225

Full name of sole or first inventor (Nom complet de l'unique ou premier inventeur)	Citizenship (Nationalité)	Date (dd/mm/yyyy) (jj/mm/aaaa)
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43 rue Fortin, Asbestos, Quebec, Canada, J1T 4E5		
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(200) Jérôme Cros	Canadian	21/12/2001
Residence and Post Office address (Domicile et adresse postale) CAX	Second Inventor's signature (signature du second inventeur)	
770 rue Belvédère, apt. 7, Québec, Québec, Canada, G1S 3E5		
Full name of third co-inventor (Nom complet du troisième co-inventeur)	Citizenship (Nationalité)	Date (dd/mm/yyyy) (jj/mm/aaaa)
(300) Philippe Viarouge	Canadian	21/12/2001
Residence and Post Office address (Domicile et adresse postale) CAX	Third Inventor's signature (signature du troisième inventeur)	
933, de la Gatineau, Sainte-Foy, Québec, Canada, G1V 3A2		

French Language Declaration

Je déclare que toute les déclarations faites dans la présente sont à ma connaissance, véridiques et que toutes les déclarations faites à partir de renseignements ou de suppositions sont tenues pour véridiques; et de plus, que toutes ces déclarations ont été faites en sachant que toute fausse déclaration volontaire ou son équivalent est passible d'une amende ou d'une peine d'emprisonnement, ou des deux, en vertu de la Section 1001 du Titre 18 du Code des États-Unis, et que de telles déclarations volontairement fausses risquent de compromettre la validité de la demande de brevet ou du brevet délivré à partir de celle-ci.

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POUVOIR: En tant qu'inventeur désigné, Je nomme par la présente l'(les) avocat(s) et/ou agent(s) suivant(s), avec plein pouvoir de révocation et de substitution, chargés de poursuivre cette demande et de traiter toute affaire s'y rapportant avec l'Office des brevets et des marques: *(mentionner le nom et le numéro d'enregistrement).*

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Please send all correspondence and direct all telephone calls to: / Veuillez adresser toute correspondance et tout appel téléphonique à:

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Full name of sole or first inventor (Nom complet de l'unique ou premier inventeur)	Citizenship (Nationalité)	Date (dd/mm/yyyy) (jj/mm/aaaa)
Jean-Yves Dubé	Canadian	21/12/2001
Residence and Post Office address (Domicile et adresse postale)	Inventor's signature (signature de l'inventeur)	
43 rue Fortin, Asbestos, Quebec, Canada, J1T 4E5 CAK	Jean-Yves Dubé	
Full name of second inventor (Nom complet du second co-inventeur)	Citizenship (Nationalité)	Date (dd/mm/yyyy) (jj/mm/aaaa)
Jérôme Cros	Canadian	
Residence and Post Office address (Domicile et adresse postale)	Second Inventor's signature (signature du second inventeur)	
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Full name of third co-inventor (Nom complet du troisième co-inventeur)	Citizenship (Nationalité)	Date (dd/mm/yyyy) (jj/mm/aaaa)
Philippe Viarouge	Canadian	
Residence and Post Office address (Domicile et adresse postale)	Third Inventor's signature (signature du troisième inventeur)	
933, de la Gatineau, Sainte-Foy, Québec, Canada, G1V 3A2		